भारतीय मानक
Indian Standard

IS 16547 : 2017
(Reaffirmed 2022)

मौजूदा मृदा एवं शैल बाँधों की नींव की जॉच करने हेतु — दिशानिर्देश

Investigations for Foundation of Existing Earth and Rock Fill Dams — Guidelines

ICS 93.160

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December 2017
Price Group 2

Foundations and Foundation Treatment Sectional Committee, WRD 8

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Foundations and Foundation Treatment Sectional Committee had been approved by the Water Resources Division Council.

Geological and geotechnical conditions are one of the most important aspects of the adequacy of a dam foundation and its safety. Evaluation of the safety of an existing dam, among other things, requires that its foundation has been adequately examined, explored, and investigated so that it is as fully understood as possible.

Foundation explorations should be directed towards obtaining only such information as may be considered important to an evaluation of the dam. The exploration programme should identify the factors that critically affect the safe performance of the dam, and not develop extraneous information.

The following are the commonly employed methods in foundation investigations, and are intended to suggest scope of investigations which, when properly implemented, will facilitate diagnostic investigation methods. It is emphasized that, because of the almost largely varying geological conditions, it would be unreasonable and impractical to attempt to set guidelines for specific investigation programmes.

It is fully recognized that the specific investigation programs and studies for individual projects vary widely according to site conditions, type of dam, hazard classification, and design phase considerations.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*).' The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

INVESTIGATIONS FOR FOUNDATION OF EXISTING EARTH AND ROCK FILL DAMS — GUIDELINES

1 SCOPE

This standard lays down guidelines for determining the appropriateness and extent of geotechnical investigations and studies for dams, water retaining and other appurtenant structures. It also outlines the desirable quantity and quality of the investigations required to support design and arrive at conclusions.

2 REFERENCES

The standards listed below contain provisions which through reference in this text constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and parties to agreements based on these standards are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below:

IS No.	*Title*
1888 : 1982	Method of load test on soils (*second revision*)
1892 : 1979	Code of Practice for subsurface investigations for foundations (*first revision*)
1893 (Part 1) : 2002	Criteria for earthquake resistant design of structures: Part 1 General provisions and buildings (*first revision*)
2131 : 1981	Method for standard penetration test for soils (*first revision*)
5249 : 1992	Method of test for determination of dynamic properties of soil (*second revision*)
5529	Code of practice for *in-situ* permeability test
(Part 1) : 2013	Tests in overburden (*second revision*)
(Part 2) : 2006	Tests in bedrock (*second revision*)
6955 : 2008	Code of Practice for subsurface exploration for earth and rockfill dams (*first revision*)
7317 : 1993	Code of Practice for uniaxial jacking test for deformation modulus of rock (*first revision*)
13946	Determination of rock stress — Code of Practice
(Part 1) : 1994	Using hydraulic fracturing technique
(Part 4) : 1994	Using flat jack technique
15681 : 2006	Geological exploration by geophysical method (seismic refraction) — Code of practice
15736 : 2007	Geological exploration by geophysical method (electrical resistivity) — Code of practice

3 NEED FOR SUPPLEMENTAL INFORMATION

The preferred approach for assessing the adequacy of dam foundations should be to minimize the use of general assumptions related to foundation conditions and strength parameters. The objective of reviewing existing data is self-evident. Site-specific information and data-based analysis should be the prevalent basis for judgments on dam safety. If potentially hazardous foundation conditions are believed or determined to exist, and the existing data are insufficient to resolve the problem, supplementary investigations should be conducted and analysed, or additional information should be developed to complete the evaluation.

Typical conditions that would require additional foundation information and explorations for existing dams are given below:

a) Significant cracking, settlement or sloughing of dams or related nearby structures;

b) Increase in settlement rates or indications of movement towards downstream;

c) Uncontrolled seepage conditions under, through, and around foundations or abutments, and at the toe area of any water retaining structures;

d) Steady or sudden increase in observed seepage;

e) Credible foundation data is insufficient to support stability analysis of dam and foundation system;

f) Rapid or unexplained high rise in piezometric pressures either in the foundation or abutment material;

g) Highly fractured, jointed rock;

h) Rock formations that are known to be susceptible to seepage problems, solution activity or erodible material;

j) Rock formations that possess or have weak seams or planes with low strength characteristics and adverse orientation such as dip towards downstream, etc;
k) Change in s*eismotectonic* activity in and around the dam vicinity; and
m) Modification in the existing structure, if any.

4 REVIEW OF GEOLOGICAL INVESTIGATIONS

Geological Investigations already conducted or required to be taken up for review of existing structures to determine the following:

a) General geologic setting of the area at and near the project.
b) Characteristics of the foundation.
c) Seismicity of the area.

The extent of the investigations depends on the design of dam and appurtenances and the complexity of the local geology. The methods used for the investigations are dependent on the data that shall be obtained to fully understand the foundation. The investigative methods also depend on the types and size of the structures involved, and on the extent and quality of the information needed.

5 SCOPE OF INVESTIGATIONS

Existing dams without adequate available data should be evaluated as carefully as possible. The extent of required investigations should be dictated by hazard classification, nature of structure, and data already available. The investigations, when needed, should be planned to provide the engineer with information and data to answer questions on specific dam foundation safety problems and to perform dam safety analysis

For geotechnical investigations of existing dams, the extent of data needed may be relatively limited, depending on the adequacy of existing data and construction documentation and the same may only be obtained by drilling, sampling and testing that is concentrated in specific site areas or problems.

5.1 Investigations

The foundation soil/rock investigations for existing dams would primarily comprise of detailed drilling, sampling, and testing focused on specific features at the project site; and should be specifically planned to provide the engineer with information that is necessary to review design and develop cost estimate in case of any need for strengthening methods. Dynamic elastic, shear modulus and Poisson’s ratio are also required to be determined.

For rock foundations with joints/seams, proper geotechnical investigations are to be carried out to determine the strength parameters of joints and to assess the strengthening measures like grouting/rock bolting.

In case of dams being situated in seismic areas, it is important to assess from drill logs, the existence of any liquefiable strata. Standard Penetration Test (SPT) values, Cone Tip Resistance (q_c) from Cone Penetration Test (CPT) or Shear Wave Velocity (V_s) obtained by different *in-situ*/geophysical tests can be made use of to assess the liquefaction potential of the soil deposit (*see* IS 1888, IS 1892 and IS 2131). Specialist literature may be referred for determining liquefaction potential of a site as suggested in IS 1893 (Part 1). In case liquefaction potential is envisaged, suitable measures should be undertaken to improve the liquefiable foundation strata by suitable methods to mitigate/eliminate the possibility of liquefaction of soil during earthquakes.

6 METHODS OF INVESTIGATIONS

The adequacy of design of a structure will normally be primarily dependent on the extent of the information known about foundation conditions of the site and the physical properties of the foundation materials. To evaluate these properties, choice and the type and application of sampling methods is important. There is no single sampling method or sampling device that will guarantee the recovery of satisfactory sampling in all material, but the less disturbance caused to the sample, the more accurate the results will be from testing that sample. Different devices and techniques have been developed for drilling and sampling a wide variety of types of material. Proper sampling is a combination of science and art. Although many procedures have been standardized, requisite alteration and adaptation of investigation techniques are often dictated by specific requirements of design.

6.1 Types of Exploration

The general types of explorations used to investigate foundation soils fall into following four categories (*see* IS 6955):

a) Geological reconnaissance and mapping;
b) Borings, with sampling and conducting SPT, *in-situ* permeability of foundation strata;
c) Special excavations to provide access to sub-strata; and
d) Geophysical explorations.

6.2 Geological Reconnaissance and Mapping

Geological reconnaissance and mapping is crucial for understanding critical items influencing siting, design, and construction. It gives the overall picture of foundation geological condition and is very useful in evaluating any instability, settlement or seepage problems that may occur during the operation of the structure under investigation.

6.3 Borings

Out of different types of explorations, borings comprise the most practical and accurate method of obtaining sub-surface information. The most important aspect of the drilling procedures is the recovery of the *in-situ* foundation material penetrated. A boring with low recovery is of limited value. Besides, standard penetration tests may be conducted alternately with sampling at appropriate intervals. These help to assess the important soil/rock parameters required for evaluating the foundations.

6.4 Special Excavations

Special excavations are defined as those openings made manually or with machinery other than drill rigs for the purpose of obtaining soil or rock samples, or conducting *in-situ* testing. They consist of test pits, test trenches, large diameter borings, tunnels, shafts, drifts or adits.

6.5 Geophysical Explorations

Geophysical explorations are an indirect method of obtaining generalized sub-surface geological information by using special instruments to make certain physical measurements (*see* IS 15681 and IS 15736). Geophysical observations in themselves are not geological facts, but are statistical and orderly measurements. Geophysical explorations complement core drilling, test pits data, or other direct methods of sub-surface exploration and can provide a rapid insight into the geological conditions and help evaluate some design parameters. However, their reliability is only as good as their confirmation by conventional means of explorations.

6.6 Location of Explorations

Adequate information about foundation properties and characteristics is critical to a full understanding of the adequacy of any design or in the evaluation of an existing foundation/structure. Therefore explorations should be adequately distributed over the entire foundation and influenced adjoining area and in specially required cases at appurtenant structures, including penstocks, tunnels, spillways, intakes and outlet, at the powerhouse foundations site (whether surface or sub-surface)

6.7 Laboratory Tests

Laboratory testing of foundation material may include the performance of routine tests such as direct shear, unconfined compression, triaxial shear, sliding friction, modulus of elasticity, tensile strength, natural and dry density, moisture content, consolidation, Atterberg's limits, grain-size analysis, and permeability. Tests for foundation rebound, slaking, collapsibility, dispersive characteristics, and determination of the mineral and chemical composition of the rock and ground water may be required where unusual geological conditions exist. In addition, where liquefaction potential may need to be evaluated, dynamic laboratory tests such as cyclic direct shear and/or cyclic triaxial compression tests should be conducted (*see* IS 5249).

Laboratory tests may be needed to provide information regarding the behaviour of foundation soil/rock under the various construction conditions to which it will be subjected to, such as, rebound due to removal of load, application of load, scour, exposure to weather, wet-dry, and freeze-thaw cycles. The interpretation, evaluation and application of the test results to the evaluation of foundation adequacy is a highly important aspect and depends to a great degree upon experience and judgment in correlating and weighing the data accumulated in the test program.

6.8 Field Tests

One of the most important field tests performed is permeability. Permeability tests can be done either by pumping out or by applying hydraulic pressure [*see* IS 5529 (Part 1) and IS 5529 (Part 2)]. The pumping-out test consists of bailing or pumping water from wells or boreholes and observing the effect of this operation on the water level in these and nearby holes.

For evaluating the physical characteristics of the rock mass as a whole , Additional field tests such as test blasting, rock bolt pull-out tests, flat jacking tests, Goodman jacking tests, chamber tests, and direct shear test [*see* IS 7317, IS 13946 (Part 1), IS 13946 (Part 4)] may be carried out.

In special cases where foundation strata is susceptible to liquefaction potential, dynamic field tests such as cyclic plate load test and block vibration tests may be conducted (*see* IS 5249).

7 EXPLORATION

The term exploration as used in this phase of the geotechnical investigation refers to the sub-surface work performed at the dam foundation site; it includes such items as soil and rock borings and field testing and evaluations. Explorations are normally confined to foundation materials through the body of the dam unless there are explicit reasons for exploration in separated areas such as on upstream or downstream through the bed in to the foundation. Conditions which may call for additional investigation may include such features as cavernous limestone foundations.

The exploration serves several functions which should include the specific items noted below:

a) Identification of the soil horizons in foundation, that is, soils with differing properties for engineering purposes.
b) Obtaining soil samples for subsequent laboratory testing.
c) Performance of field tests which can later be used to corroborate laboratory test results.

The number and location of borings which form the bulk of the exploration will vary, depending on the height and length of the dam, geological conditions in the area and the complexity of the dam.

8 MINIMUM BORING LAYOUT

The following is a suggested minimum boring program that can establish a reasonable basis for getting required information for any desired subsequent analyzer.

a) One (1) crest boring extending through the embankment and foundation materials to bedrock for each 100 m of crest length, arranged such that one boring is located at or reasonably near the maximum section.
b) One (1) crest boring extending through the embankment and foundation materials to bedrock near each abutment; these borings should be located such that the phreatic line should be intercepted.
c) If access is reasonably attainable (side slopes not steeper than 3H : 1V or berms are present), one boring extending through the embankment and foundation materials to bedrock near each abutment near the mid height of the dam on the downstream slope of the dam; additional borings on the downstream slope should, if attainable, be taken at intervals not to exceed 10 m.
d) One (1) boring opposite each boring advanced from the crest extending through the foundation material to bedrock along the toe of the dam.

NOTES

1 All borings should extend into the foundation material a minimum depth of half the heights of the embankment or to bedrock. Borings may be terminated in foundation soils when they penetrate a ‘firm, impervious’ stratum which will not settle, fail in shear or permit excessive seepage. This determination requires considerable judgment in certain cases and experience is very important.

2 Generally, to better establish the rock line, soil horizons and phreatic surface, borings on the crest, slope and at the toe should be located on or reasonably near cross-sections through the dam.

3 All proposed borings should be accurately located on a boring plan and the elevation information noted on the boring log. The boring plan and logs should be plotted on scale drawings for ease of use.

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This Indian Standard has been developed from Doc No.: WRD 08 (0636).

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

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Published by BIS, New Delhi